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Importance of Grass Carp (*Ctenopharyngodon idella*) for Controlling of Aquatic Vegetation

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Abstract

Aquatic plants are beneficial and a necessary part of lakes and reservoirs. Also, some kind of plants are the main food source for aquatic animals. Plants are able to stabilize sediments, improve water clarity and add diversity to the shallow areas of lakes. On the other hand, overgrown plants can become a nuisance by hindering human uses of water and threaten the structure and function of diverse native aquatic ecosystems. This chapter aims to make analysis of using of grass carp to control aquatic vegetation. In this concept, origin and distribution, biological features, reproduction, feeding behaviour and effects of grass carp on aquatic plants, water body and sediments are also discussed.

Keywords: aquatic plants, grass carp, biological control, ecology, habitat

1. Introduction

Aquatic plants are important elements in water reservoirs. They play a fundamental role in energy and carbon storage at the bases of food pyramids. In addition, they act as protection and reproduction refuges for many organisms, and its submerged parts allow the development of periphyton communities [1].

Unfortunately, as beneficial as they are, aquatic plants can easily overpopulate and become a nuisance to the landowner. Plants can also harm the fishing potential of the water body. An excess of decaying plants can lower the amount of oxygen in the water that can be harmful for the aquatic species. In some waters, abundance of plants overprotects fish and other prey species allowing them to overpopulate.

Controlling and eliminating aquatic vegetation from ponds are often confusing and frustrating tasks. The selection of a vegetation control program depends on local conditions of the pond. For this aim, there are three approaches including mechanical, chemical and biological control. First one is the mechanical control which involves physical removal of the vegetation and is often more difficult in water than on land. Second, chemical vegetation control is often unsuccessful, and retreatment may be needed. Also, chemical vegetation control can become expensive, and the selection of a chemical depends on the plant species involved. In addition, chemical vegetation control is short lived due to most of aquatic herbicides that do not persist more than a few months.

For these reasons, the ideal aquatic plant management tool should provide cost effective control with long-term impact, a high level of selectivity and if possible have minimal or no negative side effects. Another alternative control method to mechanical or chemical vegetation control is biological control which involves using of fishes to control the aquatic vegetation. Biological control has many advantages over the other vegetation control means. For instance, it takes much less human work effort than most of mechanical control means and does not require using expensive and hazardous aquatic herbicides. In addition, using fish species provides longer term control than other control mechanisms due to fishes that usually have a life-span of several years.

Fish used for aquatic vegetation control include several species of tilapia (*Tilapia* spp.), silver carp (*Hypophthalmichthys molitrix*) and the grass carp (*Ctenopharyngodon idella*). Of these fish, only the grass carp is able to consume large quantities of aquatic macrophytes [2]. Under suitable conditions, adult grass carp can consume more than its own weight of plant material on a daily basis [3].

From this point of view, controlling aquatic vegetation with grass carp is one of the available options for pond owners with aquatic plant problems. In many situations, using grass carp is an economical, long-lasting and effective option.

2. The grass carp

Grass carp (*C. idella*), also known as the white Amur, is one of the most important farmed freshwater fish species with an annual global production of 5,537,794 tons in the year of 2014 [4]. The grass carp is one of the largest members of the family *Cyprinidae* and is the only member of the genus *Ctenopharyngodon* [5, 6]. It shouldn't be confused with other carp species such as silver carp (*Hypophthalmichthys molitrix*), bighead carp (*Hypophthalmichthys nobilis*) or mud carp (*Cirrhinus molitorella*) These carp species are not good biological control agents for aquatic vegetation because they feed on different components of the pond ecosystem.

Grass carp is native to southeastern Russia and northwestern China. This herbivorous species has been deliberately introduced into many countries for vegetation control purposes. In addition, the grass carp is an integral part of fish culture and forms an important source of protein for human consumption.

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2.1. Distribution of grass carp

Grass carp is a sub-tropical-to-temperate species and is native to large rivers and lakes in eastern Asia. Its native range extends from southern Russia southward to northern Vietnam and in large rivers like the Amur (border of China and Russia), Yang Tze (northern China), Yellow River (central China), and the Min River (crosses the border from Vietnam into China) [5].

In addition, grass carp have been introduced to many countries around the world including Taiwan, Israel, Japan, the Philippines, the United States, Mexico, India, Malaysia, the Netherlands, Switzerland, Czechia, Slovakia, Denmark, Sweden, Romania, Poland, Italy, West Germany, France, the United Kingdom, Argentina, Venezuela, Fiji, New Zealand, Australia and South Africa [5].

Grass carp are considered uncommon in their Amur basin native range, relative to other species of Asian carps. There is a broad range of climatic conditions within the native range of the grass carp. The mean annual air temperatures range from 25°C (in the southernmost part of the hemisphere) to −60°C (in the northernmost part of the hemisphere) [5].

2.2. Biological features of grass carp

Grass carp is characterized with a wide and scale-less head, sub-terminal or terminal mouth with simple lips which do not include barbels, protracted upper jaw and a very short snout [7–9].

The body is slender and rather compressed with a rounded belly and slightly decurved lateral line [9]. Dorsal fin origin is above or just in front of the pelvic fin origin and the dorsal and anal fins do not have spines [5, 10]. Cycloid scales are dark-edged with a black spot at the base, and the gill rakers are short, lanceolate and widely set [7, 9]. Pharyngeal teeth are bi-serial and are 2.5–4.2, 2.4–4.2, 2.4–5.2 or 1.4–5.2 [5]. Diploid chromosome number is n = 48 and biochemical analysis of five tissues revealed an estimated 49 loci [9]. The colour of adult grass carp is dark grey on the dorsal surface with lighter sides (white to yellow) that have a slightly golden shine. Fins are clear to grey-brown colour [7].

2.3. Reproduction of grass carp

Mature grass carp require approximately 1500 to 2000 days within a year for gonadal development and maturation [11]. Maturity occurs at earlier ages and smaller sizes in tropical climates [5] which is between the ages of 1 to 8 years in the introduced and cultured grass carp populations. Grass carp males generally mature 1 year earlier than females at 50–86 cm in length [5].

In grass carp, the external sexual dimorphism appears in adults at the onset of maturity with the appearance of tubercles on the dorsal and medial surfaces of the pectoral fins in males. Temporary tubercles may develop in females, but they are not as highly developed as in the males. Females exhibit soft, bulging abdomens and swollen, pinkish vents at onset of maturity [5].

On the other hand in some temperate regions, in spite of grass carp maturing at the same time as in their native distribution, their gonads do not mature. This is possibly related to a lack of nutritional, photoperiod and water temperature requirements for grass carp [12]. A well-marked and limited spawning season occurs in temperate latitudes. On the other hand, in tropical areas, the breeding season expands and becomes less distinct, and as a result of this, multiple spawning can occur in a year [5].

In their native areas, grass carp begin migration to spawning areas when water temperatures reach 15–17°C [6]. Water temperature and its level play key roles for inducing spawning, and it varies with latitude. Water temperature required for the stimulation of sexual maturation and spawning ranges between 20 and 30°C. Optimum spawning temperature is generally thought to be between 20 and 22°C. In addition, increases in water level exceeding 122 cm within a 12-hour period are required for spawning [6]. If water levels do not rise during the spawning season, females with small reserves of body fat will either release no eggs or release only a portion. Non-released eggs are subsequently absorbed in the body [13].

Grass carp spawn in the rivers and canals during high water. Spawning usually takes place in spring and summer in the upper part of the water column over rapids or sand bars [5]. Preferred spawning habitat is found in turbulent water of the junction of rivers or below dams [14, 15]. Grass carp prefer to spawn in water currents ranging from 0.6 and 1.5 m/sec, but spawns generally occur in currents as low as 0.2 m/sec or even in ponds where the current is absent [15].

Fecundity is directly proportional to length, weight and age of the females and ranges from 0.001- to 2-million eggs but generally averages to 0.5 million for a 5-kg broodstock [5, 6]. Grass carp eggs are 2.0–2.5 mm in diameter when released but quickly swell to a diameter of 5–6 mm as water is absorbed [6]. The eggs are semi-buoyant and nonadhesive, requiring well-oxygenated water and a current to keep them suspended until hatching [6, 15, 16]. Eggs may travel along the downstream, that's about 50–180 km [14].

2.4. Feeding behaviour of grass carp

Grass carp feed almost exclusively on aquatic plants. They can eat 2–3 times their weight each day and may gain 2–4 kg in a single year. The larger they get, the more plant material they consume. Cultured grass carp may reach up to 1 kg in the first year and grow approximately 2–3 kg/year in temperate areas and 4.5 kg/year in tropical areas [5].

Grass carp prefer soft and low fibre aquatic vegetation such as duckweed and various underwater plants. If the more desired plant species aren't available, they feed on plants above of the water surface. Grass carp even have been observed to feed on terrestrial plants that are hanging over the water. Triploid and diploid grass carp seem to consume similar quantities of aquatic plants and to have similar feeding habits and prefer succulent young plants. Because of its strong preference for aquatic vegetation, the grass carp is being widely used to control aquatic vegetation in lakes and ponds [7].

The five most-preferred species in order of preference are hydrilla, musk grass, pondweeds (*Potamogeton* spp.), southern naiad (*Najas guadalupensis*) and Brazilian elodea (*Egeria densa*) [17]. Grass carp are not a good control method for filamentous algae, Eurasian milfoil (*Myriophyllum* *spicatum*), spatterdock (*Nuphar advena*), fragrant water lily (*Nymphaea odorata*), sedge (*Cladium* spp.), cattail (*Typha* spp.) or other large aquatic plants [18]. Factors such as age, size, temperature, availability of plant species, size of waterbody and stocking density (in pond cultures) may influence grass carp feeding strategies [9].

While active feeding begins at 7–8°C, intensive feeding occurs only when water temperature is at least 20°C [16]. Three or four days after hatching, larval grass carp begin feeding on rotifers and protozoans, moving up to larger cladocerans at 11–15 days after hatch [9, 14]. By 2 weeks after hatching, grass carp feed on larger prey such as daphnia and insect larvae [9, 14]. After 3 weeks, the occurrence of plants in the diet increases with the appearance of filamentous algae and macrophytes. Macrophyte feeding begins from 1 to 1.5 months after hatching [9]. However, juveniles consume other items including chironomids, cladocerans, copepods, insects and their aquatic larvae, crustaceans and small fishes [6].

Studies indicate that grass carp lose weight when kept in unvegetated ponds with sufficient animal food sources [19]. When the supply of macrophytes is low, adult grass carps are able to utilize other food sources including benthos, zooplankton, water beetles and crayfishes [16]. Lopinot [20] indicated that grass carp feeds on almost anything when vegetated food is scarce including small fishes, worms and insects, but in pond culture, they seem to prefer pelleted food to vegetation.

3. The method

Intensive use of chemical fertilizers in agriculture and also human and industrial pollution causes eutrophication. This situation causes growing of plants quickly and as a result of this, plant control cannot be solved mechanically or chemically. The most obvious solution in these cases is the introduction of grass carp to these waters covered with plants.

Some several thousand hectares of large ponds covered with overgrown macrophytic vegetation can be cleaned by introducing of grass carp. Grass carp is one of the optimal species for controlling of aquatic plants in water reservoirs. At this point, several parameters such as stocking density of grass carp, plant and plankton composition, water quality, and also the structure of the benthos should be noted.

3.1. Stocking of grass carp for controlling of aquatic vegetation

The grass carp number required to control aquatic plants varies depending on the degree of plant infestations, plant types, pond sizes and the size of fishes stocked. A number of different methodologies have been used to determine the suitable number of grass carp to stock. The most precise method is to determine the weight of aquatic vegetation in the pond and knowing the consumption rates of the fish.

In spite of investigation of different stocking rates, there is no guideline that will fit all situations for grass carp. Each aquatic reservoir is different because of its own combination of fertility, water clarity, shallow water and chemical makeup. So, each of these variables affects the number of grass carp required to achieve the plant level to the desired control. Stocking rates may vary as low as one to as many as 20 grass carp per acre, depending on the amount and types of vegetation.

Stocking rates need to be increased as temperature decreases (as indicated by daily temperature units (DTU) decrease) because grass carp plant consumption and growth decrease. Stocking densities need to be based on the standing crop (biomass) of aquatic vegetation. This is estimated by multiplying plant distribution by average plant density; therefore, the higher the vegetation biomass, the higher the required stocking rate.

It should be well known that "overstocking" is followed by complete removal of all vegetation, while "understocking" of a water body causes either selective reduction of vegetation [21] or it can also result in no vegetation [22]. Low stocking densities can maintain intermediate plant control. On the other hand, plants rejected by the grass carp are left and may grow vigorously [23].

The amount of aquatic plants consumed by grass carp and its selectivity depends on many factors such as stocking density, age, temperature conditions, the length of time the fish have been in the pond and the quality and quantity of food present.

Initial plant density is an important indicator for the biological control. Biocontrol is effective if grass carp is stocked prior to the beginning of the rapid vegetation growth. Water level fluctuation should be estimated and taken into consideration. A dramatic decrease of water level could cause overstocking of the grass carp, and it is extremely difficult to remove fish from lakes. For this reason, stocking density of grass carp should be calculated for the lowest water level.

In addition to these, grass carp age and size are also important due to the possible predation on them, which can markedly reduce their initial stocking density. Grass carp should be larger than 30 cm when stocked; otherwise, they are very vulnerable to predators. In some areas, the otter can capture grass carp of about 2.7 kg (length of 60 cm), causing serious problems for fishpond management [24].

3.2. Changes in aquatic plant pattern and plankton composition

Grass carp can continuously control preferred aquatic plant species. Their impacts have been observed for 15–20 years at higher stocking rates. It is assumed that elimination of aquatic plant species preferred by the grass carp results in reduction of the diversity of the aquatic macrophyte community [25].

The stocking density and controlled plant area affect the extension of phytoplankton production in the ponds or lakes. In case of slow controlling of plants by grass carp, the indirect consequences of grass carp stocking on phytoplankton are negligible. It was determined that changes in the concentration of chlorophyll-a in the water were non-significant at low stocking density (30 kg ha^{-1}) [26]. Cassani et al. [27] also determined that in case of suppression of macrophytes, annual mean chlorophyll-a concentration remained stable in the ponds.

Primary production of the water reservoirs depends on light and nutrient availability. These two factors affect unstable equilibrium between macrophytes and phytoplankton. For this reason, the speed and extent of macrophyte removal by the grass carp affect the phytoplankton production.

Zooplankton consumption is necessary for juvenile and adult grass carp, but the consumed amounts are negligible in case the stocking density is not extremely high [28]. In lakes stocked with herbivorous fish, the growth of zooplankton and zoobenthos is enhanced through consumption of macrophytes by the fish and subsequently increased nutrient remineralization rates. The overall result can be also demonstrated through an increase of fish production [29]. Finally, the zooplankton communities shifted from copepod and copepod-cladoceran-dominated communities to rotifer and small cladocerans. Changes in zooplankton abundance and community structure were due to an increase in phytoplankton and shifts in planktivore predation on zooplankton by fish after macrophyte removal [30].

3.3. Changes in water quality and benthos

The effects of grass carp on plants and water quality are highly variable and often inconclusive due to the lack of proper control sites. The proportion and rate of plant removal by the grass carp is crucial. Changes in water quality as a result of plant removal by the grass carp mostly occur in small, non-flowing water bodies and least occur when only a small proportion of plants is removed from large, relatively deep, flowing reservoirs. In this concept, decreases can be observed in oxygen concentration of water following grass carp stocking, depending on the disappearance of macrophytes [31]. Primary producers such as phytoplankton and aquatic macrophytes not only release oxygen but also consume CO_2 during photosynthesis, which results in an increase in water pH. Changes in oxygen concentrations following grass carp stocking were positively correlated with the changes in pH [32].

Higher stocking densities of grass carp or their longer impact can increase concentrations of nutrients in the water, but these increases are mainly dependent on the water-body characteristics. These changes result from sediment resuspension during feeding and faecal matter deposition by carp as well as collapse of mechanisms responsible for maintenance of the vegetated state due to removal of macrophytes. Changes in benthos corresponded closely to changes in aquatic vegetation which stabilize sediments and provide additional substrate in the form of root masses and decaying material. Zoobenthos also responded to changes in water quality following removal of aquatic macrophytes [33].

The rate of aquatic plants elimination determines the magnitude of impact [30, 34]. These changes in water quality are often followed by algal blooms [35] which in most lakes signal a shift to an alternative stable state [36]. Increasing rates of nutrient cycling following resuspension of sediments lead to decreases in ecosystem stability [37].

4. Conclusion

In conclusion, grass carp can be effective in controlling of aquatic plants, but its potential adverse effects to aquatic ecosystems may be severe. In this concept, changes in plant abundance and community composition occur due to foraging activities, alteration of water transparency, disturbance of the sediment and deposition of faecal matter by grass carp. In addition, grass carp introductions may lead to unsuitable changes in the plant community. For this reason, risks and benefits of grass carp use should be considered, and necessary measures should be taken to control aquatic vegetation before stocking of grass carp to the aquatic environment.

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